SECTION II.—GENERAL METEOROLOGY.

A CORRELATION OF WEATHER CONDITIONS AND PRODUCTION OF COTTON IN TEXAS.

By JOSEPH BURTON KINCER.

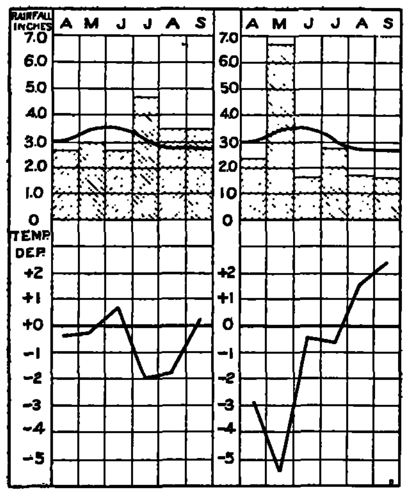
[Dated: Weather Bureau, Washington, D. C., Mar. 31, 1915.]

Every farmer, whether he be operating on progressive and scientific principles by advanced and approved methods of agriculture, or laboring under the handicaps incident to failure or refusal to adopt such methods, realizes the importance of favorable weather as a copartner, so to speak, in this the greatest and most important of all industries. Soil fertility, it is true, is an important factor in determining whether the returns shall be large or small, but it must take second place, as fertility and approved methods of cultivation would avail but little without favorable conditions as to moisture and temperature. It is also well known that in regions where the amount of rainfall and the temperature conditions are such as to ordinarily meet the requirements of plant growth, unfavorable meteorological conditions frequently occur, with a corresponding reduction in yield from what it would have been under more favorable circumstances, if not resulting in almost complete failure. In general, the more pronounced the unfavorable conditions, the greater is this reduction in yield, in view of which a direct relation between weather and crop production is obvious; but this relation had until recently been known only in a general, vague, and indefinite way and the matter had received but little consideration. However, with the advent of the new science of agricultural meteorology the importance of the question and the broad field offered by it for scientific study and investigation presented themselves so forcibly that the matter could no longer be ignored and much has been accomplished already toward establishing a physical relation between meteorology and plant development.

It is the purpose of this paper to briefly discuss this relation from a practical standpoint as applied to the production of cotton in the State of Texas, but it has been found feasible at this time to consider only the meteorological elements of precipitation and temperature, of which the former unquestionably is the more important and should receive the greater consideration.

It is realized that if certain difficulties, from a correlation standpoint, in the measuring of precipitation could be overcome, it would be preferable to consider a more limited territory as a unit area, but under present conditions it is thought best to consider the State as a whole. The usual summer type of precipitation is that of local showers, instead of comparatively uniform amounts over extended areas, as in the winter type with its pronounced cyclonic action. The summer showers frequently occur as heavy falls over limited areas in comparatively short periods of time, a large portion of which often contributes nothing to the development of the plants, but runs off and is lost, in so far as the ultimate result on production is concerned. If we attempt to correlate precipitation with yield under these conditions, ignoring the intensity of the falls and the resulting run-off, it is obvious that no reliable relation could be established, as we include in our computations varying amounts of water that flowed into the streams and rivers without contributing anything to the development of the plants. In the State of Texas these excessive local falls are, as a rule, of comparatively infrequent occurrence, and by considering the State as a whole, with its numerous reporting stations, this difficulty is largely overcome, or at least is reduced to a minimum.

We shall take as a base for computation the normal temperature and rainfall for the State, and attempt to correlate the actual departures from these mean values with the departures from the average yield of cotton, expressed in pounds per acre. The normal rainfall used in the computations represents a smoothed curve for the computed normals for the State, with monthly values as follows: April, 3 inches; May, 3.5; June, 3.5; July, 3; August, 2.8, and September, 2.8



1. 2.

FIGS. 1 and 2.—Shaded blocks in upper portion of diagrams show average monthly precipitation, as indicated by figures at the left, and the heavy solid lines show the normal rainfall for the respective months.

The monthly temperature departures from the normal are shown by the heavy lines in the lower part of the diagrams.

We shall assume that the greater the departures of rainfall and temperature from the normal values during the planting and growing season, covered by the months named, the smaller will be the yield of cotton. The logic of this assumption is clearly shown by a comparison of the departures of rainfall and temperature with the resulting yields for a series of years. In this connection attention is invited to figs. 1 and 2, which represent graphically the monthly rainfall and temperature departures from the normal for the State of Texas for the years 1906 and 1907, respectively. It will be noted that in 1906 the departures from the normals were small, while in 1907 they were large. The yield for the former year was 225 pounds per acre, or about 32 per cent above the average, while for the latter it was only 130 pounds per acre, or about 26 per cent below the average.

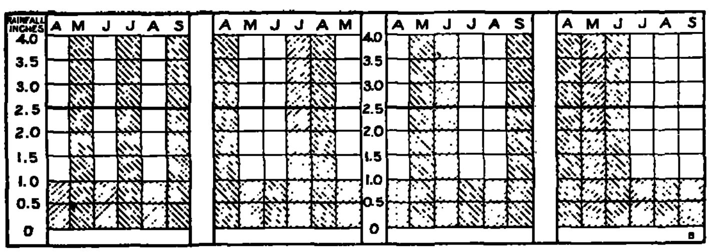
These facts give us the germ of a measurement from which a skeleton equation may be written, thus,

$$X = a + b, \tag{1}$$

where X represents the departure of yield from the average, a the departure of rainfall, and b the departure of temperature from the normal.

However, some necessary and important modifications of this equation must be made before practical application is feasible. In the first place the normal rainfall and temperature would not produce an average yield, but, on the contrary under such conditions, the yield would be much above that value, as is clearly indicated by figure 1. Again, the first member of this equation (the departure from the average yield) may be positive or negative, depending on whether the weather conditions had been favorable or unfavorable, and this sign must be indicated for practical application. Furthermore, some unit period of time must be adopted from which to obtain values for the second member. Obviously we could not consider the departures from the normal rainfall and temperature for the season as a whole, for large values could obtain on either side of the normal for the first half of the season and equally large departures on the opposite side for the last half, which, combined, would give values for the season as a whole, equal to the seasonal normal; thus superficially indicating favorable conditions, which in fact would have been most unfavorable. In view of this the calendar months of the growing season have been adopted as unit periods for deriving values for a and b.

Before we can logically apply the observed values for rainfall and temperature, they must be modified by the assignment of auxiliary factors to represent the modifying influence of certain associated combinations of rainfall and temperature conditions, of condition of the soil at the beginning of each month, and of intensified effect due to long sustained periods of unfavorable weather. Figures 3, 4, 5, and 6 illustrate these points. These represent four hypothetical conditions of rainfall, covering the six months of the growing season.



3. 4. 5. 6.

FIGS. 3, 4, 5, 6.—Four hypothetical rainfall conditions, illustrating different distributions during the growing season as affecting ultimate production. The shaded blocks show the average monthly rainfall, as indicated by the figures at the left, and the heavy solid line indicates the normal rainfall.

In each of these cases the normal rainfall is represented as being 2.5 inches for each month, and the accumulated departure for the season as a whole is the same in each instance, the latter value being zero. A knowledge of the general effect of rainfall conditions on plant development demonstrates that the production would vary greatly for these years. They are arranged in order of their value from the standpoint of yield, figure 3 being the most favorable for the production of a large yield and figure 6 the least favorable. In the first figure we find the departures alternating from month to month, which means, for example, that each month of deficient rainfall begins with the soil well supplied with moisture, thereby ameliorating the droughty conditions; also the periods of drought are of comparatively short duration. Again each month of excessive rainfall begins with the soil comparatively dry, in which condition it can accommodate more than the usual amount of rainfall without detriment to the growing plants. In figure 4 a drought prevails in May and June, but these are the cultivating months and such condition affords excellent opportunity for thorough cultivation and assures a crop free of grass. Figure 5 indicates conditions more unfavorable; May and June are perhaps too wet for proper cultivation, while July and August present a more or less serious drought, coming in the fruiting season. Figure 6 indicates conditions obviously most unfavorable; the excessive rainfall in the first half of the season not only prevents proper cultivation, but encourages shallow root growth, which proves disastrous during the long drought to follow.

Figure 7, which was also published in the October, 1914, issue of the National Weather and Crop Bulletin, shows graphically the weekly rainfall and temperature conditions during the growing season of 1914 for the States of Texas and Oklahoma, and also the percentage of

COTTON REGION.

Western Section: Texas and Oklahoma.

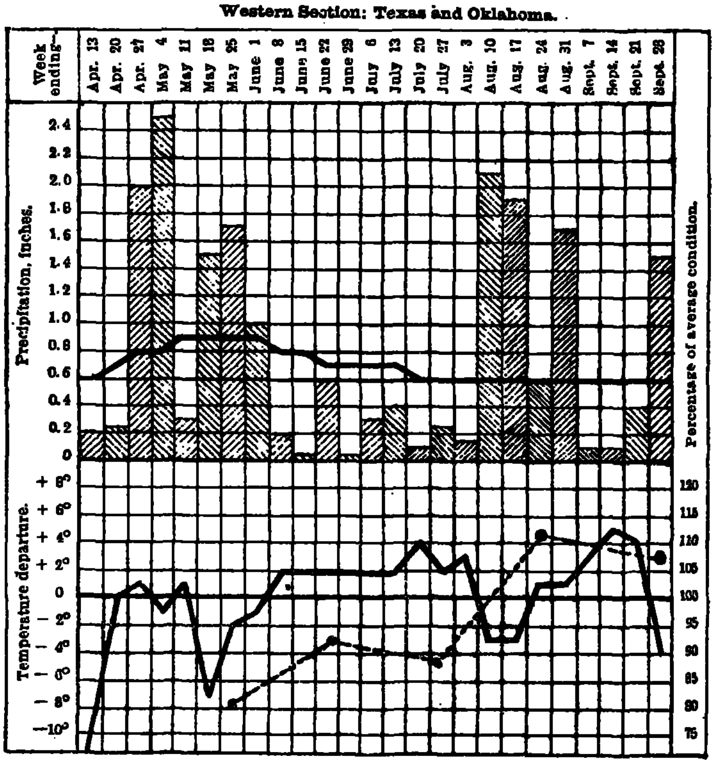


FIG. 7.—Shaded blocks in upper part of the diagram show average weekly precipitation as indicated by figures at left, and the heavy solid line indicates the normal weekly precipitation.

The weekly temperature departures from the normal are shown by the heavy black line in the lower part of the diagram, the amount of departures, in degrees, being indicated by the figures on the left. The percentage of the average condition of cotton on the dates indicated is shown by the dotted line, the amounts above or below 100 per cent being indicated by the figures on the right.

average condition of the cotton crop in those States on the 25th of the respective months from May to September, inclusive, as reported by the Bureau of Crop Estimates, Department of Agriculture. This figure very forcibly fortifies the argument that the amount of rainfall or departure from the normal for a definite period of time can not, under certain conditions, logically or practically be considered independently of preceding conditions in correlating rainfall with crop yield. The diagram shows that a more or less serious drought began the 1st of June and ended about the 1st of August, but that this drought was preceded by excessive precipitation. The accumulated minus departure of rainfall for the first four weeks of the drought, ending June 29 or four days after the June report of the crop condition, was considerably greater than for the second four weeks, ending July 27 or two days after the July report of condition. Notwithstanding this larger departure for the first four weeks, the report of condition shows a substantial improvement in the crop for that period, while for the second period a considerable deterioration is noted. Considering the fact that the soil was thoroughly saturated at the beginning of the first period, with dry, warm weather needed, and that the soil moisture was largely depleted at the beginning of the second, the condition of the crop as indicated at the end of the respective periods was such as would logically be expected.

Likewise in considering temperature departures from the normal, the season in which they occur and their relation to the moisture condition for the period under consideration, as well as their duration at abnormal values, must be considered. For example, a given negative temperature departure with excessive rainfall during the spring months, e. g., May and June, would be more harmful than a like condition during a midsummer month. The temperature is normally lower and rainfall normally higher for the spring months, and this, in addition to the temperature requirement of the young plant during its early growth, renders the conditions stated more detrimental than if occurring later in the season. Still further, a positive temperature departure with deficient rainfall for the summer months is more harmful than a negative departure with like rainfall conditions, especially if the rainfall has been deficient for a considerable length of time, as excessive heat favors evaporation and thus further depletes the soil moisture.

This matter has been considered at some length to emphasize the fact that in practical application the observed values of a and b must be modified by the introduction of auxiliary factors, thus,

$$X = (ac + bc_1), \tag{2}$$

where c and c_1 represent the relative weights to be assigned to a and b. However the expression $(ac+bc_1)$ represents the departures for a single month. To obtain a value for the whole season the equation becomes,

$$X = \frac{(ac+bc_1)_1 + (ac+bc_1)_2 \ldots + (ac+bc_1)_n}{n}$$

$$= \frac{\Sigma(ac+bc_1)}{n}, \tag{3}$$

where Σ stands for the summation of all the quantities denoted by $(ac+bc_1)$, and n is the number of months in the season.

The values assigned to the auxiliary factors c and c_1, for the 20-year period, 1894 to 1913, inclusive, are given in the following tables. In Table 1 are entered the values for c, and in Table 2 those for c_1. These are of necessity arbitrarily or empirically fixed, but are assigned after a careful study of weather conditions for the period named, in conjunction with the resulting yield for the respective years, and from a general knowledge of the effect on plant development of certain combinations of weather. A careful study of the tables will disclose logical relations.

Under rainfall we can have four conditions: (1) a month of plus departure following a month of like departure; (2) a month of plus departure following a minus departure; (3) a month of minus departure following a like sign; (4) a month of minus departure following the opposite sign. The values assigned to c in each case are as follows:

TABLE 1.—*Rainfall auxiliaries; values for c.*

	Conditions.	Apr.	May.	June.	July.	Aug.	Sept.
1	+ following 0 or +	4	8	8	4	4	4
2	+ following −	4	4	2†	2†	2†	3
3	− following −*	4	5	6	8‡	10‡	8‡
4	− following 0 or +*	2	2	3	6‡	8‡	4

* Minus departures of less than 0.3 of an inch for April and May are considered as normal.

† If following 2 or more months of minus departure, substitute 1 if departure more than 1 inch; and 0 if less than 1 inch.

‡ If fourth consecutive month of minus departure, increase value by 2; fifth month by 6, and sixth month by 8; all minus departures for July and August of more than 2 inches are given a minimum value of 12.

Under temperature we can likewise have four combinations: (1) a plus temperature departure occurring with a plus rainfall departure; (2) plus temperature departure with minus rainfall departure; (3) minus temperature with minus rainfall departure; (4) minus temperature with plus rainfall departure. The values assigned to c_1 in each case are as follows:

TABLE 2.—*Temperature auxiliaries; values for c_1.*

	Conditions.	Apr.	May.	June.	July.	Aug.	Sept.
1	+ Temperature with 0 or + rainfall	1	1	1	1	1	1
2	+ Temperature with − rainfall	1	1	2†	2†	2†	1†
3	− Temperature with − rainfall ‡	1	3	2	2	2	2
4	− Temperature with + rainfall ‡	1	4	4	2	2	2

† If third month of minus rainfall increase value by 2; if the fourth, fifth, or sixth month, by 3.

‡ If third consecutive month of minus temperature departure, increase value by 1; ourth month by 2; and fifth or sixth month, by 3.

It will be noted that prolonged periods of unfavorable conditions are provided for by increased values as indicated in footnotes.

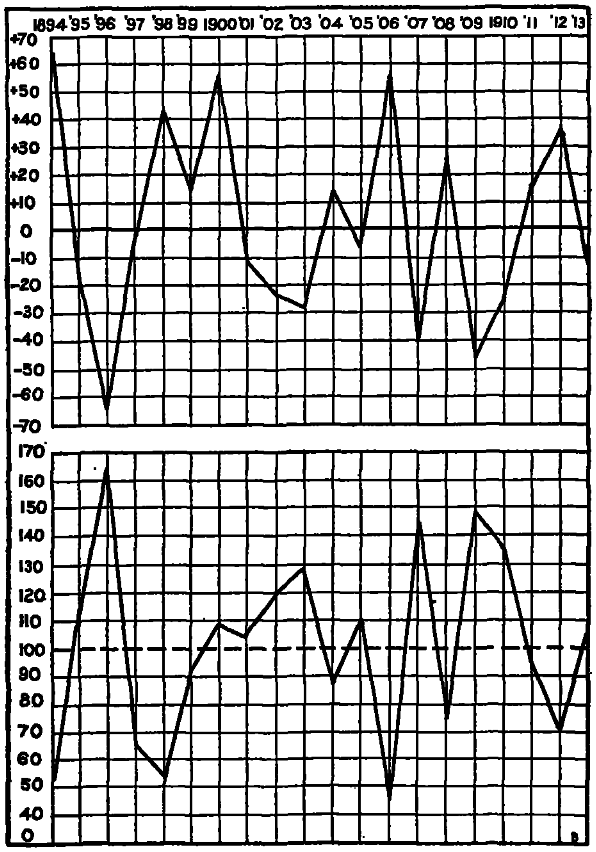
The fact that the normal temperature and rainfall would produce a yield much above the average has been briefly referred to, and this must receive further consideration before we can apply the values obtained from the departures of rainfall and temperature. By referring again to figures 1 and 2, we find in the first case that the yield was much above the average and in the second much below that value, while the departures of temperature and rainfall from the normal were small in the former and large in the latter. Obviously there must be intermediate departures that would produce values corresponding to the average yield. The value thus produced would necessarily be a constant, applicable to all years of the series. The introduction of this constant, d, completes the equation, which can now be written:

$$X = d - \frac{\Sigma(ac+bc_1)}{n}, \tag{4}$$

When $\frac{1}{n}\Sigma(ac+bc_1) < d$, X would be positive and when $\frac{1}{n}\Sigma(ac+bc_1) > d$, X would be negative. Moreover the magnitudes c and c_1 are so chosen that each unit of the final result obtained represents 1 pound of cotton per acre, thus making the computed values for rainfall and temperature departures comparable with the departure from the average yield.

TABLE 3.—*Departure of rainfall and temperature from the normal in Texas, 1894-1913.*

Months.	1894		1895		1896		1897		1898		1899		1900	
	Rainfall departure.	Temperature departure.	Rainfall departure.	Temperature departure.	Rainfall departure.	Temperature departure.	Rainfall departure.	Temperature departure.	Rainfall departure.	Temperature departure.	Rainfall departure.	Temperature departure.	Rainfall departure.	Temperature departure.
	Inch.	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*
Apr...	+0.5	+3.2	−1.3	−0.4	−1.1	+1.0	−1.0	−1.6	−0.5	−3.0	−0.1	−2.7	+3.3	−2.5
May...	−0.1	+1.0	+2.4	−2.0	−2.2	+4.4	+0.4	−0.9	−0.8	+0.8	−1.0	+2.8	+1.3	−1.2
June...	−1.0	−1.3	+1.9	−0.7	−2.5	+3.4	−0.5	+0.5	+1.9	0	+3.2	−1.1	−1.5	+1.9
July...	−0.8	−1.3	0	−0.4	−0.4	+0.2	−1.8	+1.6	−0.8	−1.2	−0.3	−0.6	+2.6	−1.5
Aug...	+2.4	−2.6	−0.6	+1.3	−1.5	+2.7	−0.3	+0.3	−0.1	+0.5	−2.0	+3.1	+0.8	−0.8
Sept...	−0.1	+0.6	−1.1	+2.8	+1.8	+0.8	−0.6	−0.4	−1.1	+1.1	−1.2	−0.3	+2.5	+3.3
	1901		1902		1903		1904		1905		1906		1907	
Apr...	−1.0	−3.3	−0.9	+1.9	−2.0	−1.8	−1.0	−1.1	+3.3	−2.0	−0.3	−0.3	−0.6	−2.9
May...	−0.1	−0.8	+0.4	+2.5	−1.2	−3.3	+1.1	−1.4	+1.3	+1.5	−0.5	−0.2	+3.2	−5.4
June...	−2.2	+1.1	−1.5	+2.6	+0.6	−4.2	+0.8	−1.2	+1.1	+0.4	−0.8	+0.7	−1.8	−0.4
July...	−0.5	+1.3	+2.8	−1.0	+2.8	−1.9	−0.3	−1.5	+1.1	−2.0	+1.7	−2.0	−0.2	−0.6
Aug...	−2.2	+2.4	−2.5	+3.1	−0.6	−0.5	−0.6	−1.2	−1.6	+1.2	+0.7	−1.8	−1.0	+1.5
Sept...	+0.6	0	+2.2	−1.3	−0.3	−0.4	+1.2	+1.4	−0.5	+2.0	+0.7	+0.2	−1.1	+2.3
	1908		1909		1910		1911		1912		1913			
Apr...	+3.1	+0.5	−1.4	−0.7	−0.4	−0.7	+1.9	0	−0.1	−0.6	−1.0	−1.6	.....	.....
May...	+2.2	+0.2	−0.4	−1.1	+0.4	−0.9	−1.4	+0.1	−1.2	+1.4	−0.9	+0.4	.....	.....
June...	−1.0	+1.2	−0.1	+1.2	−1.6	+0.4	−2.6	+3.6	+0.1	−2.7	+0.1	−2.1	.....	.....
July...	−0.1	−1.5	−0.6	+2.6	−1.6	+2.3	+0.7	0	−1.8	+1.7	−1.7	+1.2	.....	.....
Aug...	+0.2	−0.8	−0.6	+2.0	−1.6	+2.8	−0.7	+1.6	−0.3	+1.2	−1.5	+1.4	.....	.....
Sept...	+0.5	−0.8	−1.8	+1.1	−1.0	+3.5	−1.2	+5.1	−1.3	+0.8	+3.8	−3.5	.....	.....



IG. 8.—The upper curve shows for Texas the actual departures from the average yield of cotton for the respective years of the period 1894 to 1913, inclusive, expressed in pounds per acre.

The lower curve presents the computed values resulting from the application of equation (3) to the respective rainfall and temperature departures given in Table 3.

The constant d.—The monthly departures of rainfall and temperature for the period under consideration are given in Table 3. By applying equation (3) to the departures for each of the years considered, we obtain values of varying magnitude, and, if our correlation stands, we should have small totals corresponding to large yields and large totals to small yields. By charting these values in conjunction with each other; that is, the totals obtained by computation, with the departure of yield from the average, for the respective years, the connecting lines should show a similarity, but have opposite directions. Figure 8 represents the result of this correlation, the upper curve representing the departures of yield from the average, and the lower one the values for the respective years as obtained by computation. In general these curves show a similarity, as expected.

Now, if a line be drawn through the lower curve to correspond with that in the upper representing the average yield, we find that it has a value of exactly 100 points above the base; it is represented by the broken line in the lower curve. This gives us a value for the constant d, viz, 100, which means simply that a total value of 100 points computed from rainfall and temperature departures is necessary to represent the average yield of cotton. All values smaller than this constant would produce a yield above the average and those larger a yield less than the average.

Table 4, column 1, gives the actual departures of yield and column 2 the computed departures. These results are indicated graphically in figure 9, where the solid line represents the actual departures and the broken one the computed values.

We compute from these results a correlation coefficient of $+0.88$, and a probable error of ± 0.03.

As the final result is obtained from the separate monthly values, the condition at the close of any month could be readily computed and expressed in percentage of the average, thus indicating the outlook at that particular time.

TABLE 4.—*Comparison of actual with computed departures of crops from normal yield.*

Years.	Actual departures.	Computed departures.
	Lbs./Acre.	*Lbs./Acre.*
1894	+65	+46
1895	−19	−14
1896	−64	−64
1897	− 5	+34
1898	+42	+47
1899	+15	+ 8
1900	+56	− 9
1901	−11	− 6
1902	−22	−20
1903	−27	−29
1904	+13	+13
1905	− 6	−10
1906	+55	+54
1907	−40	−44
1908	+26	+24
1909	−45	−48
1910	−25	−36
1911	+16	+ 5
1912	+36	+30
1913	−14	− 6

By referring again to figure 9 it will be noted that for the year 1900 the actual yield was much above the average, while the indicated yield was slightly below that value. An examination of the records of rainfall for individual stations for that year discloses the fact that very abnormal conditions obtained. The monthly averages for the State were above the normals for all of the months, save one, of the entire season, and for several months they were much above that value. However, the large average departures for the State were more apparent than really representative. For example, in July we find eight stations with an average rainfall of more than 16 inches, while a like number had an average of less than 1.5 inches. Thus the excessive falls for more or less limited areas elevated the State average much above a representative value, thereby giving large departures from the normal and correspondingly small computed yield.

To overcome the difficulties presented by such abnormal conditions, it is believed that in correlations of this character, especially for limited areas and for regions where the summer rainfall frequently occurs in excessive amounts, some method of considering for such excessive falls only that portion that is actually absorbed by the soil, so far as this can be ascertained, should be devised. While it may not be practicable to ascertain these proportions definitely, yet by actual measurement of the water content of the soil at frequent intervals, or by measuring this content before and after rainfalls of varying intensities when runoff occurs, the relation of intensity of fall to runoff could probably be approximately determined. Also, it probably would be feasible to actually measure the runoff for selected limited areas where drainage is effected at a single point, by measuring

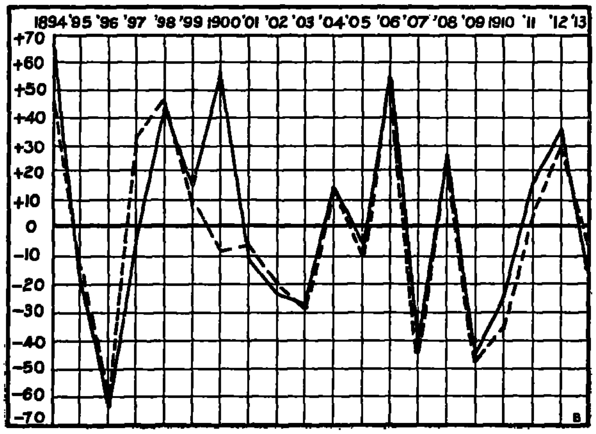


FIG. 9.—The solid line shows the actual departures of yield from the average, expressed in pounds per acre.
The broken line shows the values computed by the application of equation (4) to the departures given in Table 3.

the actual discharge at that point and reducing this to a uniform equivalent of water depth over the entire area. Again, an approximate relation might be established by careful, direct, or personal observations of soil condition and approximate runoff for falls of varying intensities, and the knowledge thus acquired could be utilized to advantage in compiling precipitation data for correlating purposes, as most original records indicate the time of beginning and ending of each rain and the total fall recorded. While only the approximate relation between intensity and runoff could be obtained by this last method, unquestionably it would afford better values of rainfall for correlating purposes than are obtained by accepting the recorded totals, irrespective of whether the entire amount was retained by the soil and utilized in the development of the plants, or a large proportion lost by runoff.

RELATION OF CLIMATE TO PLANT GROWTH IN MARYLAND.

By FORMAN T. MCLEAN.

[Dated: Johns Hopkins University, Baltimore, Md., Mar. 17, 1915.]

INTRODUCTION.

More and more attention is being paid to the relation between climatic conditions and plant growth by students of agriculture, forestry, and climatology. Progress in plant physiology and in agriculture, ecology, and forestry has made it quite clear that the growth of plants is definitely related to the nature of the environmental conditions. This principle has been most successfully applied to studies bearing on irrigation, cultivation, the use of fertilizers, etc. Regarding the relations between the plant and its environment above the soil, however, very little has yet been accomplished. These surroundings of the plant above the soil are the conditions usually termed climatic, and they have been very thoroughly studied by climatologists, but climatological study has seldom had plant relations as its main aim. Similarly, comparative studies of plant phenomena, such as growth, respiration, photosynthesis, and seed production, have not usually been carried out with the idea of relating them directly to climate. It is thus not at all surprising that the data of climatology and those of plant ecology have not been very satisfactorily correlated.

It therefore appears desirable to attack this problem of the climatic relations of plants by methods which are especially planned to bring out, as far as may be, possible correlations between the plant processes on the one hand and climatic conditions on the other. The work here to be considered is a preliminary and rather tentative attempt in this direction. It was carried on under the auspices of the Maryland State Weather Service, to the director of which, Prof. William Bullock Clark, the general project owes its beginning. The work was under the immediate direction of Prof. Burton E. Livingston, to whom the writer most gratefully acknowledges his indebtedness for his suggestions and assistance both in planning the study and in presenting the results. The author also expresses his thanks to Dr. Oliver L. Fassig, of the United States Weather Bureau, for valued assistance in presenting and interpreting the weather data; and his most sincere appreciation to the eight cooperative weather observers, who not only very kindly permitted us to use their private grounds for the experiment plots, but also kept special records in addition to the regular weather observations. We mention with deepest regret the loss of one of the observers, Mr. J. S. Harris, of Coleman, Md. The other observers who assisted in this study are Prof. A. F. Galbreath, Darlington, Md; Mr. J. H. Lawson, Monrovia, Md.; Mr. D. P. Oswald, Chewsville, Md.; President H. J. Patterson, College Park, Md.; Mr. H. Shreve, Easton, Md.; Mr. J. R. Stewart, Princess Anne, Md.; and Mr. R. E. Weber, Oakland, Md.

The previous work of the Maryland State Weather Service exemplifies the statement made above that ecological and climatic studies have usually been made quite independently of one another. "The Climate and Weather of Baltimore," by Oliver L. Fassig, and the "Climatology of Maryland," by Mr. F. J. Walz, represent very complete studies of the climate of the State, and Dr. Forrest Shreve's "Plant Life of Maryland" represents a corresponding study of the distribution of types of vegetation. The fact that Maryland has received such thorough and careful attention from these two points of view makes it a particularly suitable area for comparative work on the problem before us.

The study here reported was begun in the summer of 1914, and the work of the first season was devoted largely to perfecting and testing methods, so that this paper will deal primarily with methods of investigation and of interpreting results.

It was planned to bring out three sorts of relations between plant growth and environment: (1) The effect of local influences of climatic conditions due to differences in topography, altitude, soil, and exposure; (2) the effects